BAE SYSTEMS

Final Report
GigE Advanced Imaging Sensor

Sponsored by:
Defense Advanced Research Projects Agency
Strategic Technology Office (STO)
Program "GigE Advanced Imaging Sensor"
ARPA Order No. Y021/00, Program Code: 8X20
Issued by DARPA/CMO under Contract No. HR0011-09-C-0045

Submitted by:

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Date Prepared: Nov 24, 2009

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
23-11.2009

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
Nov 2008 - Nov 2009

4. TITLE AND SUBTITLE
GigE Advanced Imaging Sensor

5a. CONTRACT NUMBER
HR0011-09-C-0045

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
DARPA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified/Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
An advanced sensor was developed and tested under this effort. This sensor uses an EMCCD with an active focal plane of 658 by 496 pixels, in conjunction with a controllable iris and wide field of view lens to provide situation awareness over full daylight to extreme dark conditions. The interface to the sensor is over GigE, allowing high data rate signal transmission. Intensive mechanical design was applied to advance the operating conditions of the sensor to be compliant with typical hardened military specifications. A technique was developed and implemented to calibrate the sensor response over temperature for all ambient lighting conditions. This sensor is suited to a variety of military and commercial surveillance and situational awareness applications.

15. SUBJECT TERMS
EMCCD Sensor
GigE Sensor

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
unclassified	unclassified	unclassified	SAR	8	Sunshine, Lon, Dr.
					19b. TELEPHONE NUMBER *(Include area code)* 603-885-6923

1.0 Task Objectives

The GigE Advanced Imaging Sensor program addressed communication to advanced imaging sensors.

Key objectives of the program included:

1. Incorporate latest industry standard digital communication technology (gigabit Ethernet) into existing advanced imaging sensor.
2. Design, fabricate, test and integrate advanced sensor hardware and related software drivers.
3. Explore and determine unit and system level design limits of this communication technology as applicable to advanced imaging, situation awareness and survivability systems.

2.0 Technical Problems

The Wide-Field Dynamic Range (WFDR) camera is a high sensitivity, wide field-of-regard sensor of importance to future military surveillance and survivability systems. It is intended to be used in harsh, noisy military platforms with multiple camera streams simultaneously gathered. BAE Systems will be the first to bring reliable high speed video transport into the military environment. By developing a gigabit Ethernet (GigE) video transport solution for multiple cameras with low latency and high data reliability, a flexible processing architecture will be developed that allows optimization of processor throughput for real time imaging in defense applications.

The following innovative features of this concept include:

- Digital Data Distribution -- The goal was a 200x reduction in data noise, insulating the data from interference in electrically-noisy military platforms. Prior military systems make use of analog point-to-point designs: a nominal 8-bit data acquisition of analog transmissions at best had produced 6 effective bits of analog signal. Using direct digital distribution is able to achieve at least 14 effective bits effective accuracy with a 16 bit resolution.
- Multiplexed Control and Synchronization -- Multiple video data streams can be sequenced, allowing a single board computer to gather data from multiple sensors as the host is ready for data, while the sensors operate independently in parallel. The sensors provide metadata in the digital stream, allowing knowledge of precise timing of frame acquisition. This allows images to be synchronized with platform motion.
- Embedded Design – Design for use in real time systems that meet deterministic schedules for host applications. Current analog-based systems have to estimate latency for when a commanded change to a camera setting has actually taken place. An analog frame grabber runs open-loop and continuously grabs frames regardless of their generation. A digital network allows the host to initiate exposures on command, as well as to know, with certainty, that a commanded change is in effect and data is available.
- Military Ruggedization -- Operation of surveillance video in harsh military environments, to include temperature extremes. The thermal design of the sensor required considerable

redesign from the COTS camera. Additional a reliable iris drive, with precise index sensing, allows the camera to be used under both day and night conditions.

The camera itself was essentially redesigned to develop custom electrical, mechanical, and thermal solutions to the new interface. There are only 5 boards at the front now, CCD, ADC, FPGA, USB, and CLINK with the power converter, power regulator and GigE boards at the rear of the camera, heat sunk to the case connected to the main stack via a self aligning connector. (See Figures 1 and 2.)

3.0 General Methodology

For this program, BAE Systems worked with a commercial partner, Phoenix Engineering, Inc. to develop a reliable high-speed video transport camera, suitable for the military environment. The foundation for this camera was an existing commercial camera built by Raptor Photonics, the EM247. The camera sensor is a low-light, monochrome electron-multiplication charged-coupled device (EMCCD)

The camera components were revised to meet military environmental and packaging requirements, and communications interfaces were updated in order to be integrated with a Commercial Off-the Shelf (COTS) Single Board Computer (SBC) and demonstrated in a digital system. Its performance was evaluated in a thermal environment determined by realistic military applications.

By developing a GigE video transport solution for multiple cameras with low latency and high data reliability, a flexible processing architecture has been developed that allows optimization of processor throughput for real time imaging in defense applications.

Previously, high speed video data was transported to computers via frame grabbers (analog RS-170), USB 2.0, IEEE 1394 (Firewire) or Camera Link®. Analog transport is susceptible to a noisy environment, USB 2.0 and Firewire have a 5m distance constraint, and Camera Link® requires specialized cabling and has a distance constraint of 10m. Remote cameras on military aircraft are often subject to harsh environments and are located more than 10m from the CPU.

The general use of GigE to transport video data to a processor would normally be subject to unpredictable latencies at both the camera end, where the video is converted to IP and queued for GigE transport over the GigE link, and at the PC, where data are received and transferred to memory. To prevent these latencies, BAE Systems, in conjunction with Phoenix Engineering, Inc., chose to use Pleora Technologies iPORT™ IP Engine and iPORT Hydra software to reduce these latencies and processing time. The highly efficient engine, which does not use an operating system, acquires image data, converts it to IP packets, queues it for transfer, and sends it over the GigE link.

The Automated Imaging Association (AIA) has developed a GigE protocol for vision systems called GigE Vision (GEV) to provide an open framework for image transfer and provide flexibility to system designers to use less custom and more available devices. The protocol includes standardization for device identification, control protocol, stream protocol and feature mapping file (high level to low level registers). BAE Systems adhered to the GEV protocol during the development of the GigE Advanced Imaging Sensor.

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BAE Systems' program goal was to collect real-time video data from 3 cameras over GigE at a 30Hz frame rate in a VxWorks environment. Currently, our firmware is producing data at up to approximately 35 Hz. This capability enables inclusion of this high speed digital imaging architecture into embedded processing applications and/or data recording systems.

BAE Systems approach was to take an existing Wide Field of View and Dynamic Range (WFDR) camera design that currently outputs video via analog RS-170 and digital USB 2.0, and alter the design to output video via GigE. Three cameras were built and interface to a standard PC over Ethernet and to a GMS P701 Embedded System Controller

The goal of the integrated system will be to show complete end-to-end performance of a 3 camera GigE Vision based system, communicating and streaming 30Hz frame-rate imagery to a ruggedized system controller containing a customized GMS S702 processor, and storing the received imagery to an internal hard drive. Latency and processor loading will be measured, and the recorded imagery will be evaluated against its known input to assess fidelity

4.0 Technical Results

The Table below compares the proposed design with the achieved results.

Table 1 – Camera Specifications

Specification	Current Design	Proposed Design	Tested Sensor
Optical	various	Same	
Electron Gain	0 – 15x	N/A	
Charge Multiplication. Gain	1 - 1000	Same	1 - 1000
Pixel Size	10 um	Same	10 um
Wavelength	400 – 900nm	Same	400 – 900nm
# of pixels	680 x 485 (analog) 662 x 496 (digital) (658x496 active)	662 x 496 (658x496 active)	664x497 (658x496 active)
TEC	Programmable (-20 to +30C)	Same	-20 to +30
Shutter Control	1/30th sec to 1/2000th sec	N/A	
Frame Integration	1/30th sec to 1 sec (30 frames)	N/A	
Sensor Exposure Time	500µsec to 1 sec (100µsec resolution)	Same	500µsec to 1 sec
Video I/F			
Analog	RS-170,Differential, interlaced scan, NTSC	N/A	
Digital	USB, Progressive Scan	GigE, Progressive Scan	GigE, Progressive Scan
Control Interface	RS-485, 115200 baud	Same	GigE or RS-485, 115200 baud
Frame Transfer Rate	30 frames per sec analog NTSC, ~3 frames per second digital	30 fps	35fps
Power Consumption	< 17 Watts (5w additional auxiliary heaters)	< 21 Watts	< 11 Watts @ 28V DC (<5W

Specification	Current Design	Proposed Design	Tested Sensor
			additional heater)
Weight	< 38 oz.	< 2 lbs.	2.56 lbs
Firmware Upgrades	Via USB I/F	Same	Via GigE or RS485
Connector	TBD p/n 22 pins D38999/24WC35PN	TBD p/n 22 pins	22-pin MIL-STD 38999 D38999/24JC35PA
Operating Temperature	-51ºC to +52ºC TE Cooler maintains Focal Plane at 0C from -52C to +42C external environment	-51ºC to +52ºC	-51ºC to > +60ºC 5W heater allows TE Cooler to maintain -20 ºC

5.0 Important Findings and Conclusions

The digital WFDR meets provides the desired high-resolution, high-speed imaging capability. Due to the possibility of setting the camera to long integration times and high EM gain as well as to short integration times with closed iris, the camera is capable of surveillance applications from the darkest night to the brightest day.

The camera is capable of rapid switching between different settings to grab frames. While the manufacturer's requirements allow 100ms for the camera to reach a new operating condition up changing exposure time or EM Gain, it appears that both these transitions occur much faster, enabling the camera to produce images at a new gain state at its maximum rate of over 30 Hz.

A few open issues in the development are still pending. Phoenix Engineering has committed to upgrade the three cameras delivered under this contract at no additional cost.

- Iris drive. The current iris drive functions over temperature down to -25 deg C (-13 deg F), rather than the required -51 deg C. A new iris drive has been designed for use over the full temperature scale and is being built. These are expected to be received by Phoenix mid-December 2009. Phoenix will retrofit the three cameras at no additional cost, if desired.

- Power Supply Unit noise. The new PSU has appeared to introduce some noise into the ADC. The camera manufacture has reduced this somewhat, however some noticeable noise still persists (primarily quantitatively, but much less so visibly). This noise is most observable at high EM gains, where it causes the lowest several (usually 5) bits of the image samples to be set to 0. This causes image samples to be quantized to the closest multiple of 32, which is not visible at high EM gains. At lower EM gains, a faint pattern can, at times, be distinguished in the image under the right conditions. It is believed that these two effects are the same, and Raptor Photonics is investigating the root cause.

- Firmware updates. There are a few other firmware updates required to bring the cameras into compliance with the specified requirements. These updates are deemed to be of a minor nature with little or no technical risk.

6.0 Significant Hardware Development

To provide a GigE output, Phoenix Engineering, Inc. has modified the current camera design to include a COTS conversion module that converts a Camera Link® input to a GigE output. Specifically, a slightly modified PT1000VB iPORT™ device from Pleora Industries has been used. The Camera Link® input, although not present in the previous WFDR, had been used in other Phoenix cameras, and so the design was implemented in a re-spin of one of the WFDR CCAs. In addition to these two boards and a modified power board, the improvement of the existing thermal heat plane has improved the thermal management of the current design and accommodated an expected additional two watts generated by the PT1000VB.

The thermal design of the sensor required significant creativity and analysis to bring the sensor into compliance with military temperature ranges. This challenge exceeded our subcontractor's level of proficiency, requiring BAE Systems to step in and provide assistance. Several design iterations were needed to build confidence prior to build. This delayed the program from its original schedule. Final testing of the sensor has shown that the resulting design meets the specified operating conditions.

Schematics showing the difference between the old and new camera internals are shown in

Figure and 2.

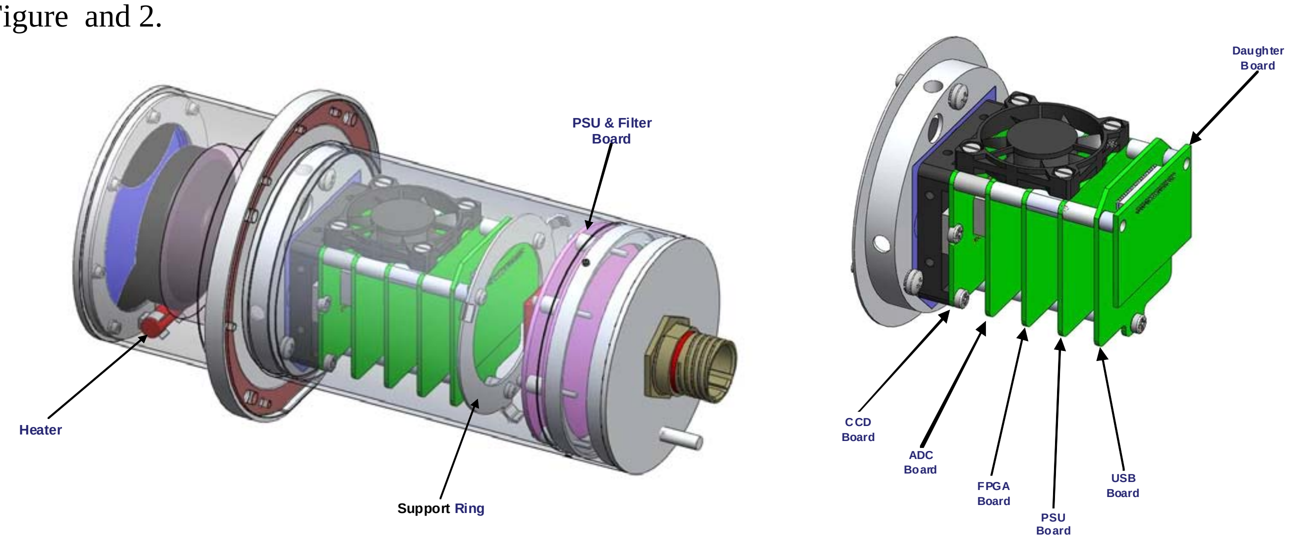

Figure 1 – Prior WFDR Camera Design

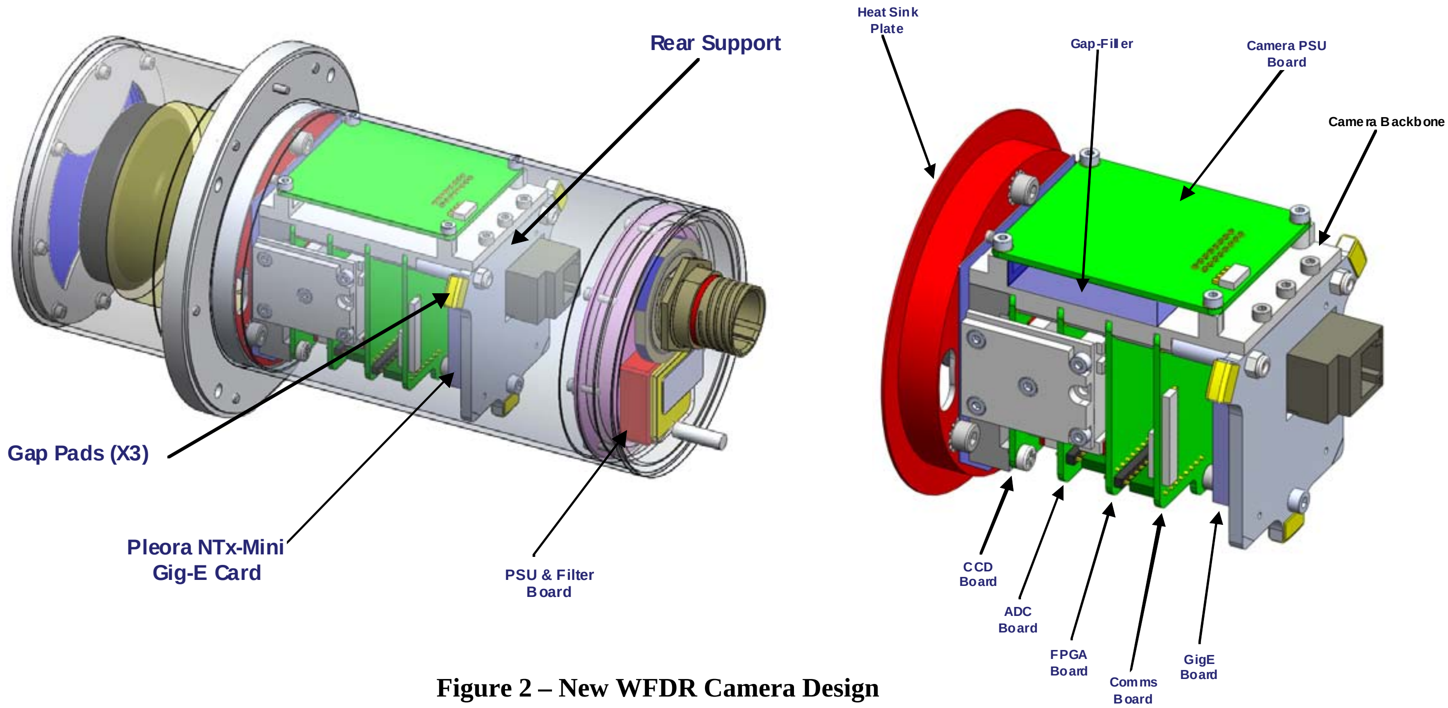

Figure 2 – New WFDR Camera Design

7.0 Special Comments

The cameras communicate using Gigabit Ethernet Vision (GigE Vision) protocol as the standard between the controller and sensors. GigE Vision is a standard for image transfer that employs the widely used Gigabit Ethernet connection (1 Gb/s). Leveraging this emerging camera interface standard has many advantages. Existing hardware including network interface cards, CAT-6 cable, and other communications devices can be used to connect our three sensors to the controller. This interface will also allow an easy upgrade to 10GigE (10 Gb/s) when that hardware becomes available in ruggedized form and our sensor progresses to 10GigE. Using the GigE Vision protocol allows interoperability of hardware and software from different vendors.

The enabling of fast image transfers through use of the GigE Vision standard is a feature that is a great improvement over the previous WFDR. Another useful feature is the predictable timing of image transfers.

Our prior system included an RS-485 connection for communications and an RS-170 connection for analog (NTSC) video. In addition to the poor synchronization between messages commands and the video stream, the system incurred a transient penalty whenever camera settings are changed, as the video needs to slew across settings.

With GigE Vision, timing is predictable and will allow the system to function smoothly. By transferring images quickly and predictably the system will greatly improve its performance. The

GigE Vision standard also allows for up to 100m cable lengths, which allows the sensor to be distributed as required.

The main detractor from using GigE, is that four twisted pair of wires (not including the optional RS-485) is required for communication whereas the analog WFDR required two twisted pairs (RS-170 and RS-485). The increased weight is a suitable tradeoff for the increased speed and performance of the overall system.

8.0 Implications for Further Research

On the controller end, the development of the GigE Vision driver was a complex undertaking. The driver processing occurs one layer up from the media layers (layer 4) and operate directly on the packet datagrams received by the SBC's GigE network interface controller (NIC). While several NIC manufacturers are developing GEV interfaces for their products, none of the efforts to-date have intended for use in an RTOS environment.

The GEV interface to the camera is functional and now needs to undergo the rigors of thorough testing under conditions of other desired applications. Additionally, more rigorous timing and some environmental tests to identify the boundaries of performance should be conducted, to expand the scope of applicability of these cameras. Also, while our current product solution uses three separate Ethernets to control the camera, the suitability of multiplexing all devices onto one Ethernet should be tested, and limitations thereof determined.

Finally, the root cause of the PSU noise, described in Section 5.0 should be fully determined, isolated, and ultimately removed.

9.0 Standard Form 298, August 1998

Standard Form 298 is attached.